Human Spaceflight Capabilities

Spacesuit Trauma Countermeasure System for Intravehicular and Extravehicular Activities

Completed Technology Project (2011 - 2014)

Project Introduction

The objective of this research is to understand human-space suit interaction and design hardware to assess and mitigate injury and discomfort inside the space suit. This will be achieved through the following specific aims.

1.1.1 Specific Aim 1: Analyze data for correlations between anthropometry, space suit components, and injury. Shoulder injuries are some of the most serious and debilitating injuries associated with EVA (extravehicular activity) training. Using a database compiled by NASA personnel on subject anthropometry, training time in different space suit components, and reported shoulder incidents, the following hypotheses will be evaluated:

Hypothesis 1: Anthropometric dimensions will be a predictive factor in identifying astronauts with a reported shoulder incident.

Hypothesis 2: Suit training variables in the planar hard upper torso (HUT), rather than training in the pivoted HUT, will be a predictive factor in identifying astronauts with a reported shoulder incident. Suit training variables are defined by aggregating training information, such number of or percentage of training incidences in the planar or pivoted HUT.

Hypothesis 3: Operational training variables will be a predictive factor in identifying astronauts with a reported shoulder incident. Operational training variables are defined by aggregating training information, such as frequency of training, accumulation of days between training incidences, or career duration of active duty training.

Hypothesis 4: Record of previous injury will be a predictive factor in identifying astronauts with an additional shoulder incident.

Each of these hypotheses investigates a specific causal mechanism found in the literature associated with EVA shoulder injuries and relates it to a reported shoulder incident. Hypothesis 4 will only be evaluated for those subjects with injury incidents directly attributable to the space suit.

1.1.2 Specific Aim 2: Quantify and evaluate human-space suit interaction with a suite of sensors. There is currently no method by which to measure how the person moves inside the space suit. Focusing on the upper body, a pressure sensing tool will be created to quantify human-space suit interaction under different loading regimes. Additionally, a commercially purchased pressure sensing tool will be used over the shoulder under the space suit Hard Upper Torso (HUT). Finally, inertial measurement units (IMUs) will be used to measure and assess kinematics both of the suit and the person inside.

The following design requirements will be evaluated to determine the success or failure in designing a wearable pressure sensing garment for the space suit environment:

Design Requirement 1: A pressure sensing tool will achieve both high

Spacesuit Trauma Countermeasure System for Intravehicular and Extravehicular Activities

Table of Contents

wearability and high utility in a space suit environment. Wearability is defined by mobility, comfort, and safety of the user. Utility is defined by range, accuracy, resolution, and coverage of the sensor system.

Design Requirement 2: Human and space suit interaction characterized by interface pressures will show trends consistent with expected loading regimes. Trends are defined by sensor pressure profiles over isolated or functional tasks. Expected loading regimes are defined by subjective feedback or inferred loading based on anticipated contact.

Design Requirement 1 evaluates the performance of the pressure sensing system to ensure it is properly scoped for its intended use. Design Requirement 2 investigates the system’s ability to function properly in the environment of the space suit so its results may be interpreted with confidence.

The pressure sensing tool will be used to evaluate human-space suit interaction to assess consistency of movement. Consistency of movement is an important metric revealing fatigue or changes in biomechanical strategies, both of which could be precursors to EVA injury. The following hypothesis will be evaluated in a human subject experiment inside the space suit:

Hypothesis 5: Subjects with experience working in the space suit will perform motion tasks with consistent movement strategies. Movement strategies are defined by peak pressures averaged over trials or full time averaged pressure profiles.

The commercially purchased pressure sensing tool that is placed at the interface between the shoulder and the Hard Upper Torso will be used to quantify and analyze the pressure distributions and profiles that arise in this region, thus developing a biomechanical understanding of the potential for shoulder injury in pressurized suits. A human subject experiment was performed inside the space suit to evaluate motions and regions that are particularly prone to injury. We determine subject-specific anthropometric regions of concern by considering pressure distributions, frequency of loading, and regional pressure responses. Subject consistency is also evaluated through statistical analysis of the peak pressures.

Hypothesis 6: Subjects perform motion tasks in a consistent manner as measured by pressure values over the shoulder. The kinematic sensors (IMUs) will be used to evaluate human-space suit interaction between body motions and suit motions. Externally measureable suit kinematics may not reflect the human body’s motions inside the suit due to complex design involving non planar bearing or convolutes and pressurization. The following hypothesis will be evaluated in a human subject experiment inside the space suit:

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Center / Facility:

Johnson Space Center (JSC)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Project Manager:

Jessica R Vos

Principal Investigator:

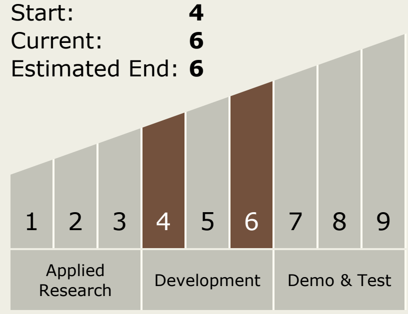
Dava J Newman

Co-Investigator:

Jeffrey A Hoffman

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Hypothesis 7: Body and suit joint angle amplitude differ significantly in amplitude for upper body motions.

Hypothesis 8: Body and suit joint angle differ significantly in axis of rotation for upper body motions. The purpose of Hypotheses 6 and 7 are to evaluate differences in suited motion between the person and the space suit. Additionally, we seek to evaluate the impairment of mobility for upper body joints in different suits, using IMUs, as compared to baseline range of motion. The following hypothesis will be evaluated in a human subject experiment inside the space suit:

Hypothesis 9: Space suit pressurization significantly impairs the joint angle amplitude of upper body motions.

1.1.3 Specific Aim 3: Model human-space suit interaction. The purpose of SA3 is to gain a better understanding of the EVA injury mechanisms, particularly strain injuries caused by the Extravehicular Mobility Unit (EMU). The objective is to determine the extent to which muscle activity is affected by the presence of the highly-pressurized space suit. A musculoskeletal human-space suit interaction model is developed in order to quantify musculoskeletal performance of astronauts during Extravehicular Activity, and to assess their injury susceptibility.

1.1.4 Specific Aim 4: Design and Develop modular protective devices. Our work develops conceptual solutions to mitigate injury. As part of this effort, we identify promising materials and build prototype protective devices. We aim to alleviate injury prone areas and improve the person’s comfort within the suit. Protective devices will be integrated to the protective garments and can be personalized for each crewmember.

Anticipated Benefits

The need to mitigate injury and discomfort is not exclusive to the harsh environment of space. The contributions from this work have the potential to be used in other extreme working environments, such as dry-suit scuba diving and high altitude pilots. In both cases, gas-pressurized suits are worn and have similar rigidity. The envisioned countermeasure and protection system capability may also be used in biomedical and rehabilitation applications. The elderly population often encounter minor trauma, but with much more severe consequences than their younger counterparts. Falls resulting in hip fractures place a disproportionate burden on healthcare costs, recovery, and death (Hayes, Myers et al. 1996). Hip injury is highly variable with position, muscle tension, and individual factors, making predicting and preventing injuries both important and challenging (Hayes, Myers et al. 1996). Injury prevention both in extreme work environments and against fall impacts for the elderly are

Technology Areas

Primary:

- TX06 Human Health, Life Support, and Habitation Systems
  - └ TX06.3 Human Health and Performance
    - └ TX06.3.2 Prevention and Countermeasures

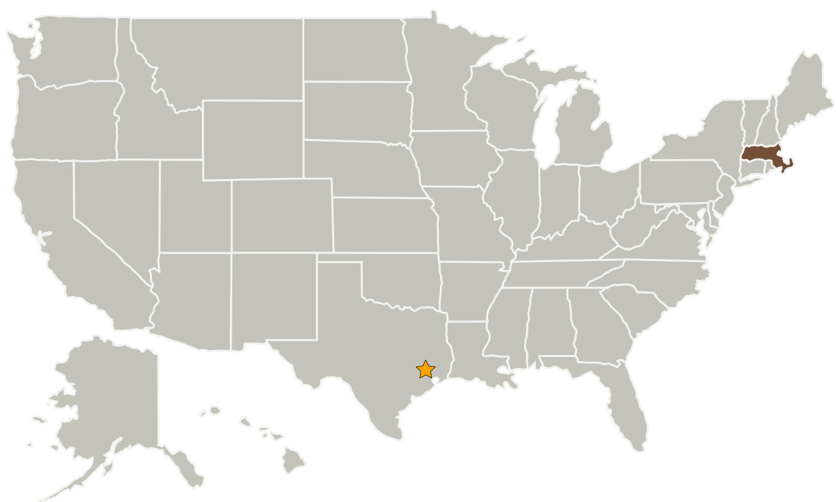
Target Destinations

The Moon, Mars

promising crossover applications. The transferability to each of these environments warrants further study.

Our team is very active in bringing our work and passion for human spaceflight to the general public through outreach. Our education and outreach efforts increase the visibility of human spaceflight and astronaut injury. We have participated in informal education through talks at museums, such as at the ExplorationWorks museum in Helena, MT where human spaceflight exhibits were developed by our team and bring space education to a chronically underserved area. We have also provided extensive outreach through many talks to the public, media, and general audiences, such as Think2012 (Goa, India), Suited for Space (American Textile History Museum; Lowell, MA), Business Innovation Forum 9 (Providence, RI). We have also given numerous tours of our lab and facilities to elementary, middle, and high school students, as well as international visitors and students from other universities. Finally, our team members have volunteered to participate in classroom teaching programs for middle and high school students. One such example is the SEED Academy developed at MIT where high school students come for 10 Saturdays and take a course in Aeronautics and Astronautics, learning about human spaceflight. Our efforts are always geared toward improving STEM (science, technology, engineering and math) education, whether in a formal classroom setting or through interactions with the general public.

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
★Johnson Space Center(JSC)	Lead Organization	NASA Center	Houston, Texas
Massachusetts Institute of Technology(MIT)	Supporting Organization	Academia	Cambridge, Massachusetts

Spacesuit Trauma Countermeasure System for Intravehicular and Extravehicular Activities

Completed Technology Project (2011 - 2014)

Primary U.S. Work Locations
Massachusetts

Project Transitions

November 2011: Project Start

November 2014: Closed out

Closeout Summary: We have completed our grant reporting period. The major contributions of our research effort are outlined below: Specific Aim 1: Statistical Shoulder Injury Analysis. The first specific aim is to analyze data for correlations between anthropometry, space suit components, and shoulder injury. Four hypotheses were proposed to relate injury to 1) body morphologies, 2) space suit HUT components, 3) training variables, and 4) previous injury. Each hypothesis was confirmed, since for both models variables for each of the first three hypotheses were identified and record of previous injury was associated with the Neutral Buoyancy Laboratory (NBL) model. The major contributions of this work are to: 1) Add quantitative statistical analysis to the causal mechanisms of injury found in the literature. 2) Provide a framework for identifying relevant predictor variables related to injury given the small number of data points, large number of predictor variables, and the differences in their distributions. 3) Identify variables related to injury which can be addressed and resolved through operational changes to training, suit design and accommodation, and identification of higher risk subjects given previous medical history. 4) Propose future areas of study for which additional data may continue to be collected and analyzed, such as HUT sizing information as related to clearance anthropometry. These contributions address the current gap in our understanding of the causal mechanisms of injury. Although HUT style has been reported as a major cause based on anecdotal evidence (Williams and Johnson 2003, Strauss 2004), it has not been until recently that this causal mechanism has been quantitatively evaluated (Scheuring, McCullouch et al., 2012). This research corroborates these findings, but expands upon them to include additional relevant factors not previously explored. It also includes other shoulder incidents, which, although not defined as medical injuries, have had negative impact on crew comfort and health, as well as impacting an astronaut's operational availability. This work also supports the conclusions reached by Williams and Johnson (2003) regarding the import of the training environment as a contributory factor, but this is the first quantitative assessment of the impacts of training frequency and recovery. Finally, it supports that suit fit is essential to achieve the optimal working environment (Benson and Rajulu 2009, Gast and Moore 2010) and allows future designs to pinpoint the most relevant anthropometric dimensions for suit fit accommodation. This work provides a quantitative analysis through data mining grounded in our historical understanding of the use of the EMU and NBL training environment. The remainder of this research allows a look forward into how additional data collection on human-space suit interaction can help prevent the occurrence of future injury and discomfort. Specific Aim 2: Experimental Evaluation of Human-space Suit Interaction. Development of a wearable pressure sensing garment. The novel Polipo low-pressure sensing system for extreme environments achieved here has many advantages. With the Polipo human-suit interaction can be measured for the first time through dynamic movement. It can accurately measure low-pressures against the body over underneath the soft-goods. The system of 12 sensors is transferrable between many different people, creating an independent stand-alone pressure-sensing system. Sensors can easily be changed to allow for improved designs or to accommodate different target pressures. The wiring was intentionally designed to achieve the best trade-off between flexibility, resistance, and stretch ability. The system achieves near shirt-sleeve mobility as sensors are moved to accommodate users. It can also be used in conjunction with a high-pressure sensing mat placed over the shoulder to measure loading between the person and HUT. The electronics architecture allows for low power onboard or real-time data collection. The entire system has been designed with extreme environments in mind, where considerations of shock, battery hazards, and material properties in mixed gas environments were minimized to ensure user safety. Finally, it has a cover shirt to slide easily over the system and prevent catching and ensure proper placement. Nearly all requirements were met and those that were not were evaluated for extent of their impact on the system performance. Therefore, this work confirms Design Requirement 1 "A pressure sensing tool will achieve both high wearability and high utility in a space suit environment." This system could easily be extrapolated to other environments where biomechanics and comfort under load needs to be evaluated, for example, soldier pack accommodation or wearable protective devices for the elderly where discomfort substantially decreases compliance. The Polipo system in its described configuration was used in a human subject experiment inside the space suit. These experiments validated the system's performance in the space suit environment and confirmed the conclusions reached after the assessment of the requirements presented here. The primary contributions of this work are to: 1) Establish baseline requirements for in-suit sensing and wearable electronics. 2) Develop pressure sensors and evaluate their performance for human movement applications. 3) Develop a wearable, stand-alone pressure-sensing system to be used for a large group of subjects in harsh working environments. 4) Create a system that is specifically targeted to provide quantitative information about human-space suit interaction not previously possible. The Polipo system as designed overcomes the issues associated with wearable electronics in that it allows for high mobility at low-pressure with less encumbrance from hardware and wired data transfer (Cork 2007; Witt and Jones 2007; Brimacomb, D. Wilson et al., 2009). It builds upon previous sensor designs (Park, Majidi et al., 2010; Park, Chen et al., 2012) to measure normal pressures targeted to the 5-60 kPa range through dynamic motion. In-suit sensing concepts have focused on traditional physiologic measures (Carr 2000, Disrnukes 2002, Catrysse 2004, Tang 2007) or display and control information (Rochlis 2000, Graziosi 2005, van Erp 2005, G

Stories

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60326)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60319)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60298)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60323)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60316)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60302)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60309)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60312)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60308)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60303)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60335)

Abstracts for Journals and Proceedings
(https://techport.nasa.gov/file/60294)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/60304)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/60305)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/60330)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/60328)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/60329)

Awards
(https://techport.nasa.gov/file/60325)

Dissertations and Theses
(https://techport.nasa.gov/file/60320)

Dissertations and Theses
(https://techport.nasa.gov/file/60327)

Dissertations and Theses
(https://techport.nasa.gov/file/60331)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60301)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60315)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60332)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60307)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60322)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60311)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60321)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60293)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60333)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60314)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60317)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60310)

Papers from Meeting Proceedings
(https://techport.nasa.gov/file/60295)

Significant Media Coverage
(https://techport.nasa.gov/file/60334)

Significant Media Coverage
(https://techport.nasa.gov/file/60324)

Significant Media Coverage
(https://techport.nasa.gov/file/60318)

Significant Media Coverage
(https://techport.nasa.gov/file/60297)

Significant Media Coverage
(https://techport.nasa.gov/file/60299)

Significant Media Coverage
(https://techport.nasa.gov/file/60296)

Significant Media Coverage
(https://techport.nasa.gov/file/60313)

Significant Media Coverage
(https://techport.nasa.gov/file/60336)

Significant Media Coverage
(https://techport.nasa.gov/file/60300)

Significant Media Coverage
(https://techport.nasa.gov/file/60306)

Project Website:

https://taskbook.nasaprs.com